Radiation Detection with Distributed Sensor Networks

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ABSTRACT

Given the heightened awareness and response to threats posed to national security, it is important to evaluate, and if possible, improve current measures being taken to ensure our nation's safety. With terrorism so prevalent in our thoughts, the possible risk of nuclear attacks remains a major concern. Portal monitors are one type of technology that may be used to combat this risk. Their purpose is to detect nuclear materials and, if found, alert first responders to such a discovery.

Los Alamos National Laboratory (LANL) is currently working on an alternative to these costly portal monitors through the Distributed Sensor Network (DSN) project. In collaboration with the University of New Mexico (UNM), this project aims to develop distributed networks of heterogeneous sensors with the ability to process data *in-situ* in order to produce real-time decisions regarding the presence of radioactive material within the network. The focus of the work described in this paper has been the evaluation of current commercial products available for application deployments, as well as the development of a sensor network in simulation to reduce key deployment issues.

1. INTRODUCTION

Distributed Sensor Networks (DSNs) are generally defined as self-organizing networks of sensors with at least a limited capability for communication and computation. A classical layout of a DSN employs the star topology of Figure 1.

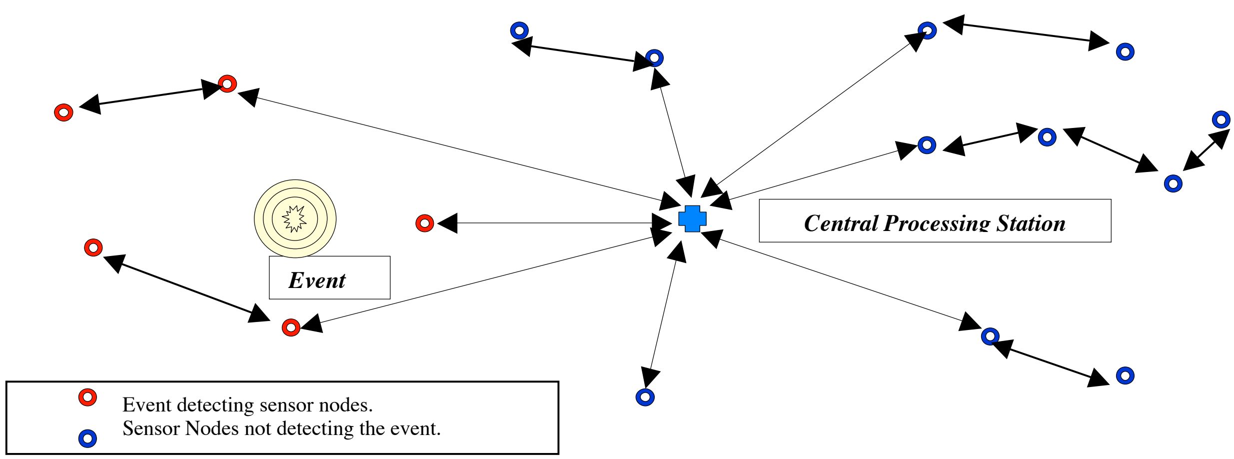

Figure 1 The star topology is the classical approach to distributed sensor network design. Data in this type of network may also be multi-hopped between the sensors before reaching the Central Processing Station.

In this type of system, sensors are deployed throughout an area of interest and communicate their raw data directly to a central processing station (CPS). This straightforward network design requires the CPS to receive the transmitted data, archive it, and process it in order to make determinations about the events occurring within the network. Although a key advantage of this topology is the ability to post-process the received data as new events of interest are identified, the potential for a catastrophic single point of failure always exists at the CPS. Additionally, if the sensors are placed at a significant distance from the CPS, long-range communication issues will need to be addressed. This network architecture is certainly viable for many applications. As research moves to ubiquitous deployments of thousands of sensors over larger regions, however, this type of architecture will produce unwieldy networks.

Instead, as applications are developed for areas such as remote sensing and persistent surveillance, alternative network designs must be developed to address the shortcomings of this classical approach. In particular, systems must be designed to both communicate and process data within the network. In this manner, the overall deployment becomes more fault tolerant since redundancy is built into the design. Data may be distilled down to key decisions in a real-time or near real-time manner. Figure 2 highlights such an alternative topology where the information from sensors across many nodes is used to draw conclusions about the event occurring within the network. Those conclusions are then passed to the end user through several redundant exfiltration nodes in a timely fashion. Although this network requires more complicated nodes and communication capabilities than the star topology in Figure 1, for many remote or covert applications it is the only real deployment option.

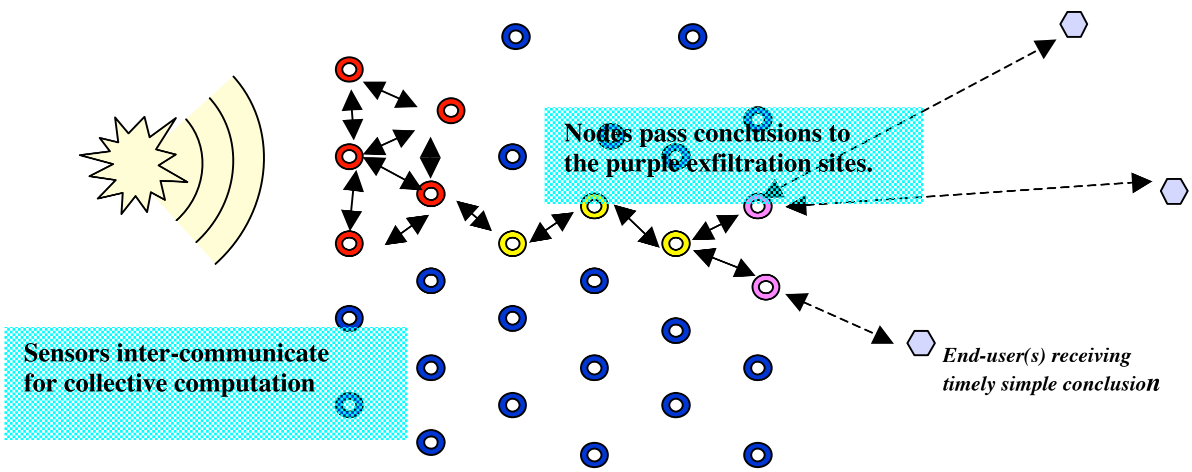

Figure 2 Network design providing for *in-situ* processing of sensor data.

Additionally, it is important to note that it is far more expensive in terms of energy to transmit data within a network using the on-board radio than it is to process the data at the microcontroller in the node. Previous work has demonstrated the cost savings in time and energy that can be attained by simply processing the sensor data within the network [1]. Figure 3 demonstrates these theoretic savings predictions for networks of various sizes. In a similar manner, by allowing nodes to employ multi-hop networking data energy efficiency is again improved, although care must be taken not to create latency issues by introducing too many data hops within the network.

Network topologies similar to that in Figure 2 are becoming increasingly viable with the recent advances in areas such as wireless networking, sensor integration and microprocessor miniaturization to name a few. The focus of our work at LANL has been on the evaluation of the viability of commercial products for remote sensing applications as well as simulation studies of a particular sensing application. The following section will focus specifically on surveying commercially available networking and sensing products. We will then highlight our simulation efforts detailing the infrastructure developed to address key deficiencies in the standard tools currently utilized by the wireless networking community. Finally, we will wrap up our discussion with a summary of our work and our aims for the future.

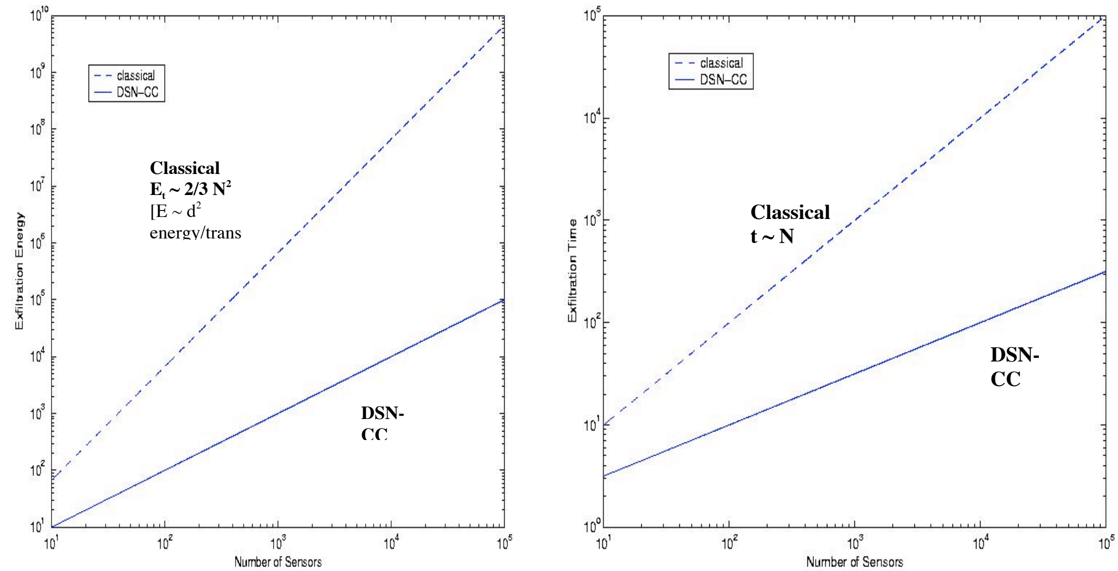

Figure 3 Theoretical predictions of exfiltration energy and exfiltration time for varying numbers of sensors within a distributed network.

2. COMMERCIAL HARDWARE

In recent years significant advances in microelectronics and miniature radio technologies have enabled the development of commercial wireless mesh networks. These products typically provide the self-organizing and self-healing backbone for the wireless transmissions and in-network processing of collected sensor data. Companies such as DUST, Crossbow, Ember and Millennial offering commercial products have sprung up over the past several years. Most products focus on the infrastructure and communication requirements of ad-hoc networks. Products such as the iB5208/0 and RT-5208/0 in Figure 4 by Millennial provide typical transmission ranges of 20-30 m with a multi-hop capability, enabling significantly longer range network development.

Figure 4 The Millennial iB5208/9 and RT-5208/9 wireless devices.

The Millennial products are very typical of the market in their focus on ultra-low power operations and ultra-long node life. All products provide the user with the ability to wire in analog and digital devices to the node boards.

Our evaluations began with early products from DUST. Several of these packaged motes are shown in Figure 5. These systems were configured quite easily and provided us with very useful configuration information, such as the information on the multi-hop routing in Figure 6.

The main issues we have with these products are their inability to deal with new nodes entering, or re-entering after brief losses, the network, and difficulty in bringing external sensor inputs into the nodes. Since our project requirements dictated the need for complex sensor data as well as self-healing wireless networking, we moved to a platform that provided a wide array of integrated sensor boards. The wireless radio platform we evaluated next for our system work was the Mica2 mote produced by Crossbow (Figure 7).

Figure 5 DUST Blue mote (top) and Sensor Expansion mote (bottom).

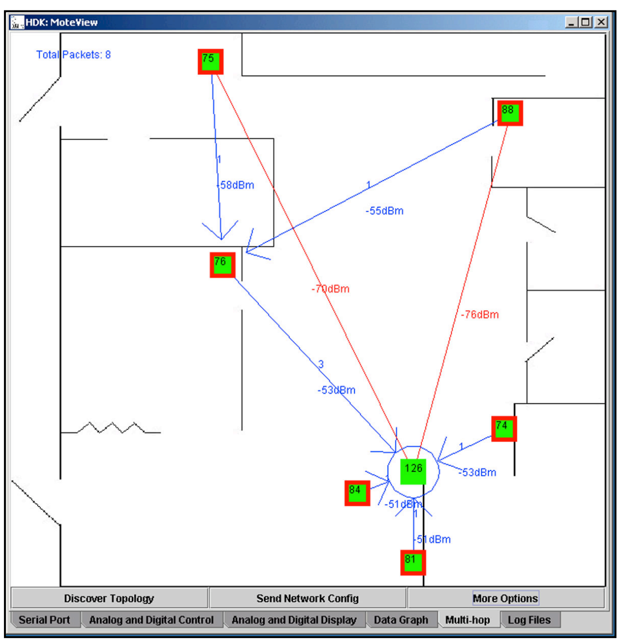

Figure 6 Each of the nodes highlighted in red represent motes. They transmit their data back to the receiving gateway node #126. The actual transmission paths are in blue along with measures of their received signal strengths.

Generally, the wireless nodes produced by various manufacturers employ very similar hardware. In fact, both the Dust Blue motes and the Crossbow Mica2 motes use the same radio chips for communication. For this reason, we will focus on a particular hardware description of the Mica2 motes with the understanding that the other products have similar characteristics.

The Mica2 radio boards are approximately the size of two AA batteries and contain both a wireless radio and a microcontroller. These devices employ the Chipcon CC1000 wireless radio with a center frequency of 916 Mhz. This radio has 50 channels available with a data rate of 38.4 kbaud and a receive sensitivity of –98 dBm. In our work, the motes, utilizing a 3 inch omnidirectional 1/4 wave whip antenna, typically exhibit a transmission range of 4.5 meters. That range may be increased to 80 meters when the devices are placed 1.2 meters off the ground. Although these values can be improved by increasing the transmission power, the tradeoff is decreased battery life.

Figure 7 Crossbow Mica2 Radio Board.

The on-board processors on the Mica2 motes are 16 Mhz, 8-bit Atmega 128L microcontrollers with 10-bit ADCs, 128 kbytes of program flash memory and 512 kbytes of serial flash. These devices may be programmed using a specialized operating system called TinyOS developed at the University of California, Berkeley.

As previously discussed, in addition to the radio boards Crossbow provides a number of sensor boards. These devices may be connected directly to the radio boards, thus pushing their data directly to the microcontroller periodically and out to the rest of the network. One board that has been investigated in particular is the MTS310 in Figure 7. It contains sensors to detect light, temperature and sound, as well as a 2-axis accelerometer and a 2-axis magnetometer. Additional boards containing GPS modules or RFID readers are also available from Crossbow.

Figure 8 Crossbow MTS310 multi-sensor board.

For more computationally intensive nodes, Personal Digital Assistant (PDA) devices may be utilized in the network. In general, these devices are moderately-sized and have moderate power usage with an 802.11b capability. Typical devices have 400 Mhz processors and may be configured with the Linux operating system. Since the start of this project, however, Crossbow has introduced the Stargate which is a 400 Mhz Xscale single board Linux-based computer with enhanced sensor signal processing and communication capabilities. This device was developed within Intel's Ubiquitous Computing Research Program and maintains the ability to directly connect to the Mica motes. Additionally, since the Stargate does not have a display, it provides significant power savings over the PDA and thus provides an excellent alternative to a standard PDA node.

The introduction of a host of products such as those described in this section has opened the doors to developers to build systems monitoring everything from roosting sea birds [2] to microclimates in redwood forests [3] to machinery in fabrication plants [3]. Generally, developers have been addressing communication or durability issues in these deployments while typically maintaining a star topology. In contrast, the focus of our simulation work remains on *in-situ* data processing in an attempt to distill the many incoming signals down to a final set of conclusions.

3. SIMULATION

Until the commercialization of the network products discussed in the previous section, research in DSN networks was completed in simulation space. Unfortunately, the most commonly utilized simulation tools for wireless network research were developed for internet routing work and neglect true wireless network constraints such as collisions and barriers without extensions. Additionally, the ability to accurately simulate environmental events was virtually nonexistent using these tools. For this reason, the Distributed Sensors Simulator (DSS) was developed at LANL in conjunction with UNM as an infrastructure for sensor network prototyping. This open-source prototype system specifically provides researchers the ability to develop realistic wireless network simulations as well as simulations of various environmental events.

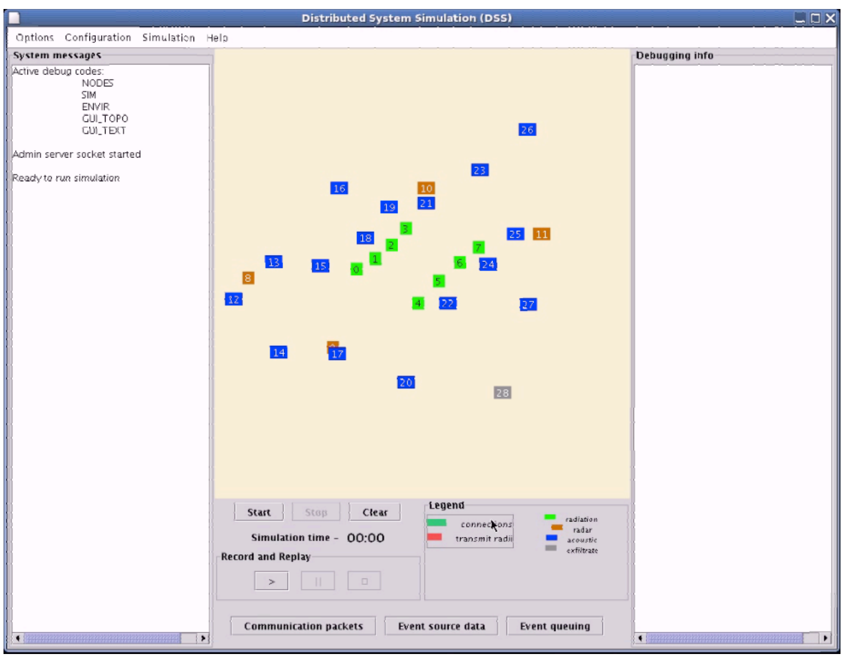

Figure 9 Roadway monitoring simulation developed in the DSS.

Simulation studies were run using DSS in order to begin system development of a network for detecting radiological material traveling down a U.S. roadway. These studies were designed to employ heterogeneous sensors each charged with a different task in the overall network. Figures 9 through 11 highlight one example run through DSS. In this example, a network of sensors is deployed along a 700 m stretch of roadway. Three types of sensor nodes are deployed. The blue nodes are acoustic sensors placed in the network to detect vehicle presence and queue up the rest of the array.

The brown nodes are radar sensors that once queued ascertain vehicle speed to the network. Finally, the green nodes are gamma counting radiation detectors. In this particular simulation, the network produces a detection if any of the independent gamma counters queued by the acoustic sensors detect radiation above background levels. Since the radar sensors and radiation sensors require significant amounts of power to maintain their readings, they are powered down until the acoustic sensors determine a vehicle presence within the network.

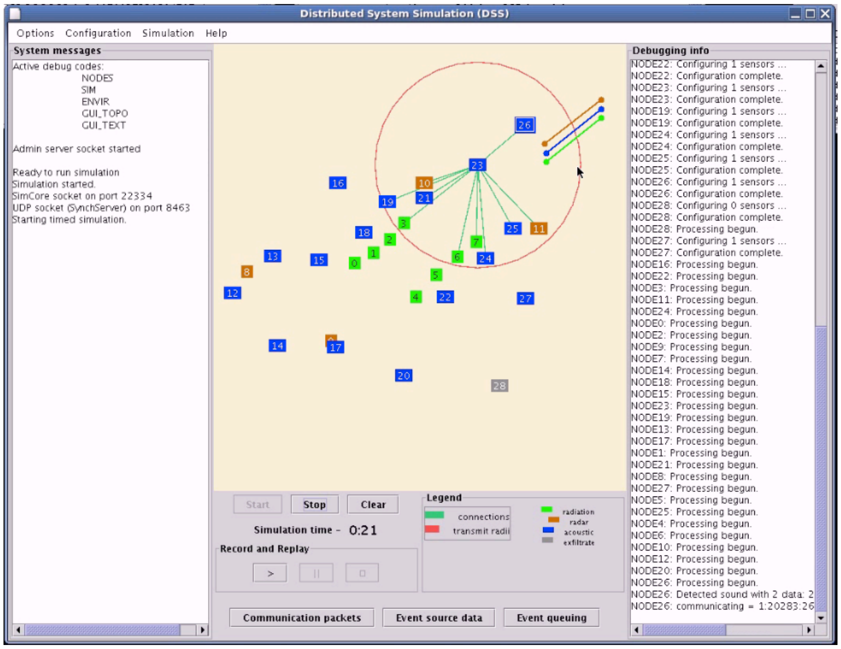

Figure 10 Simulation snapshot as the vehicle enters the array.

Figure 10 highlights the introduction of a vehicle, traveling at 45 mph, into the network with three distinct signatures (acoustic, radar and radiation). As the information is passed through the network, circles are placed around the transmitting nodes indicating their communication radius. Green lines are drawn indicating the actual transmission path of the communications. Network information does not reach the user until it is passed to the grey exfiltration node at the bottom edge of the network.

Figure 11 highlights the alert that has passed through the array to the exfiltration site. Simulations have been instrumental in our hardware integration efforts. From results obtained using DSS, we have moved to the use of magnetometers for vehicle detection instead of acoustic sensors. Similarly, we have developed algorithms utilizing statistics gathered across an entire array of radiation detectors instead of independently driven detectors [4].

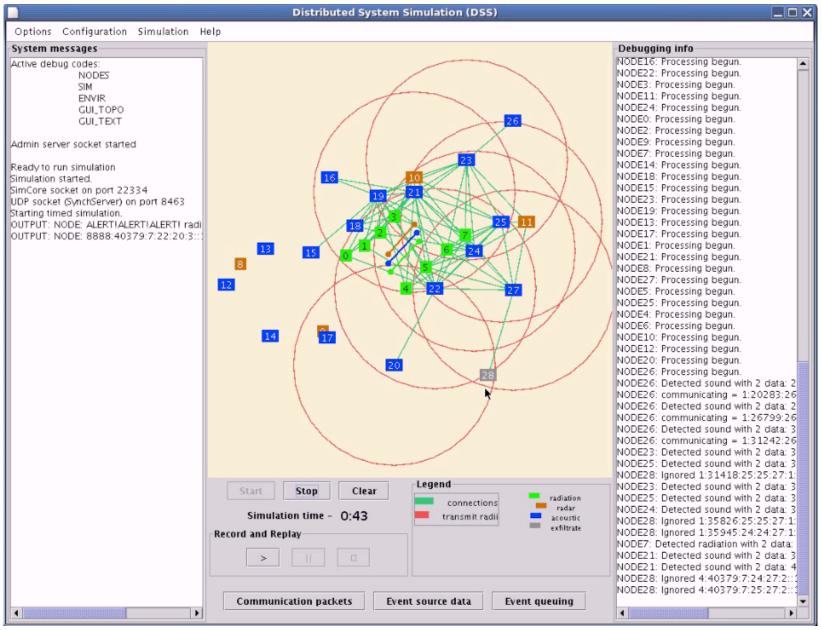

Figure 11 Simulation snapshot of the radiation detection alert being exfiltrated to the system user.

4. SUMMARY

The rapidly evolving offerings by commercial companies are driving the continuous advancement of applications utilizing wireless mesh networks. With so many new products on the market, and the endless range of potential uses, the need to develop systems in simulation becomes more compelling. As we have seen in our work, it is much simpler to change sensor type in a simulation study than to reintegrate and redeploy hardware using new sensors. By tying the studies to actual hardware implementations, it is possible to more efficiently develop prototype systems while validating those simulations. With this in mind, we are currently working on the next version of the DSS system that will provide emulation capabilities allowing the user to port the software and algorithms directly from a simulation study to the hardware platforms. The new system will also mimic the domains of wireless networking and environmental sensing much more closely. Such a system will improve our ability to develop and deploy prototype systems in an efficient and timely manner.

ACKNOWLEDGMENTS

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